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Test of Hydrogen-Oxygen PEM Fuel Cell Stack at NASA Glenn Research Center

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ABSTRACT

This paper describes performance characterization tests of a 64-cell hydrogen oxygen PEM fuel cell stack at NASA Glenn Research Center in February 2003. The tests were part of NASA's ongoing effort to develop a regenerative fuel cell for aerospace energy storage applications. Purpose of the tests was to verify capability of this stack to operate within a regenerative fuel cell, and to compare performance with earlier test results recorded by the stack developer. Test results obtained include polarization performance of the stack at 50 and 100 psig system pressure, and a steady state endurance run at 100 psig. A maximum power output of 4.8 kWe was observed during polarization runs, and the stack sustained a steady power output of 4.0 kWe during the endurance run. The performance data obtained from these tests compare reasonably close to the stack developer's results although some additional spread between best to worst performing cell voltages was observed. Throughout the tests the stack demonstrated the consistent performance and repeatable behavior required for regenerative fuel cell operation.

INTRODUCTION

The NASA GRC is supporting the development of an aerospace hydrogen-oxygen regenerative fuel cell (RFC) under the Environmental Research Aircraft and Sensor Technology (ERAST) project of the Flight Research Base Program. The ERAST charter includes the development and demonstration of new technologies for unmanned aircraft that are suitable for earth science, including RFC equipped solar electric aircraft with potentially unlimited endurance. Although ERAST is an Aeronautics project, the RFC is a solar energy storage device applicable to a wide variety of space and planetary surface missions as well as high altitude solar electric flight; hence, widespread interest throughout NASA to bring this technology to a flight demonstration. Potentially the highest storage capacity and lowest weight of any non-nuclear device, an RFC flown aboard a solar electric aircraft continuously through several successive day-night cycles will provide the most convincing demonstration this technology's widespread potential has been realized. Leading up to the flight demonstration are several laboratory and full scale demonstrations of key components, such as the fuel cell stack described in this paper.

BACKGROUND

The fuel cell stack, which converts stored hydrogen and oxygen back to electrical power in the RFC, is considered the most important key component. GRC has a test stand for hydrogen-oxygen fuel cells in the Rocket Combustion Laboratory (RCL) built up for performance testing which has been in operation since January 2000. This test stand, located in test cell 24 of the RCL, can accommodate fuel cell stacks up to 72 cells producing stack currents up to 200 A. A detailed description of the test stand and operating limitations is presented in Table 1, with a schematic diagram of the thermal/fluid systems presented in Figure 1. The test cell is serviced by bottled hydrogen and oxygen supplies placed in revetments outside the building and is well ventilated, conforming to applicable safety

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TABLE 1.—HYDROGEN-OXYGEN FUEL CELL TEST STAND

Applied Conditions and Input Parameters			
Applied condition parameter	Controlled by	Range	Unit of measure
Operating pressure:			
O2 pressure	oxygen exit line back pressure regulator	0 to 400	psig
H2 pressure	hydrogen exit line back pressure regulator	0 to 400	psig
H2 to O2 stream ΔP	coordination of hydrogen and oxygen exit pressures	±25	psid
Flow rates:			
O2 flow rate	oxygen inlet mass flow controller	0 to 50	SLPM
H2 flow rate	hydrogen inlet mass flow controller	0 to 80	SLPM
Operating temperature:	(see below)	120 to 150	°F
Coolant exit temperature	PID setpoint control diverter valve WB742	70 to 140	°F
O2 inlet temperature	oxygen humidifier tank and line heaters	70 to 140	°F
H2 inlet temperature	hydrogen humidifier tank and line heaters	70 to 140	°F
Inlet humidification:			
O2 inlet dewpoint	oxygen humidifier tank and line heaters	70 to 140	°F
H2 inlet dewpoint	hydrogen humidifier tank and line heaters	70 to 140	°F
Stack current (applied load)	electronic load unit	0 to 100	amperes
Output Measurements			
Fuel cell stack performance parameters			
Stack voltage		35 to 70	volts
Individual cell voltage:			
Maximum		1.1	volts
Average		0.75 to 0.9	volts
Minimum		0.5	volts
Stack power output	voltage X current	1400 to 5250	watts

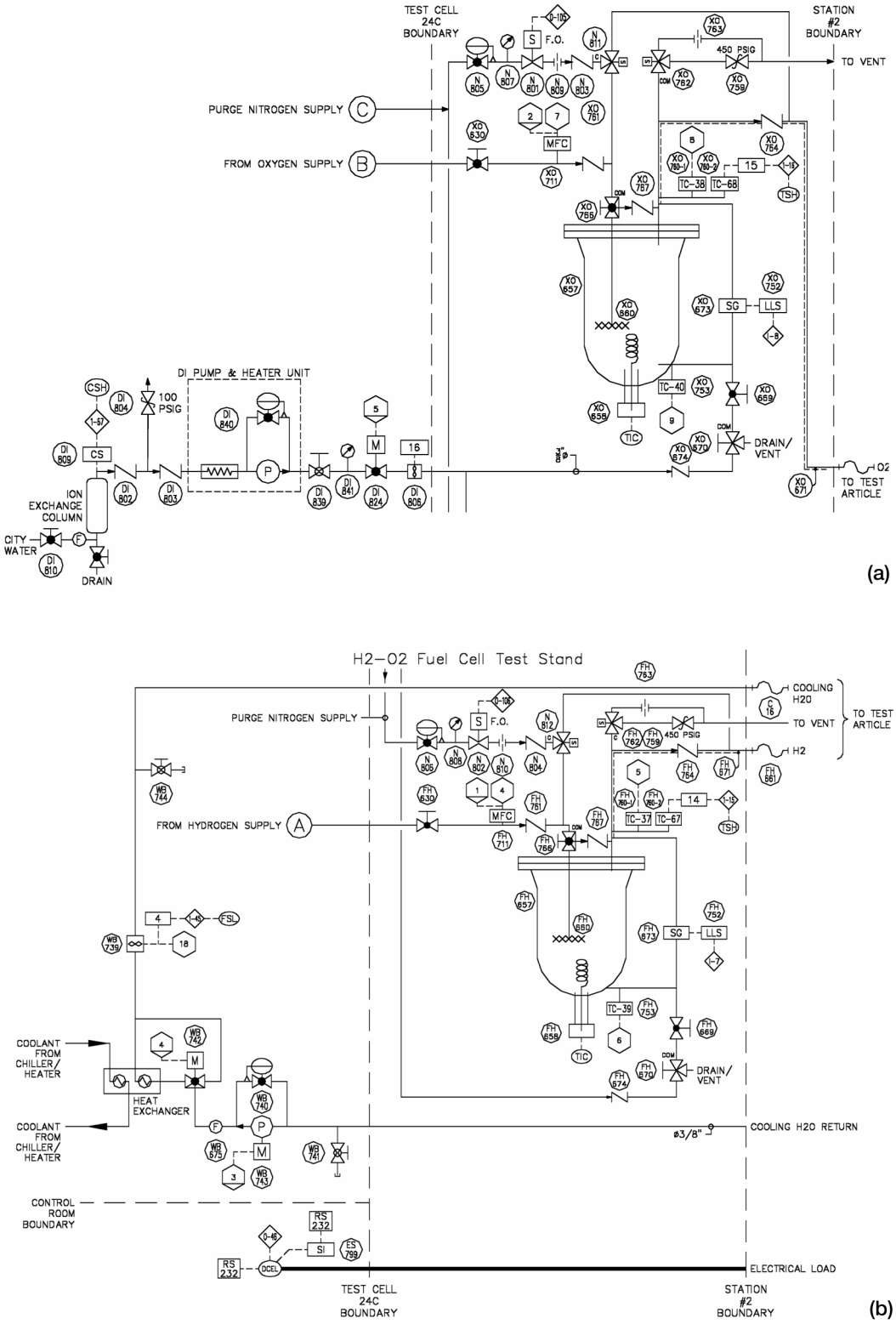

Figure 1.—H_2-O_2 fuel cell test stand at NASA GRC. (a) O_2 inlet conditioning and flow controls. (b) H_2 and coolant inlet conditioning, electrical load, and flow controls.

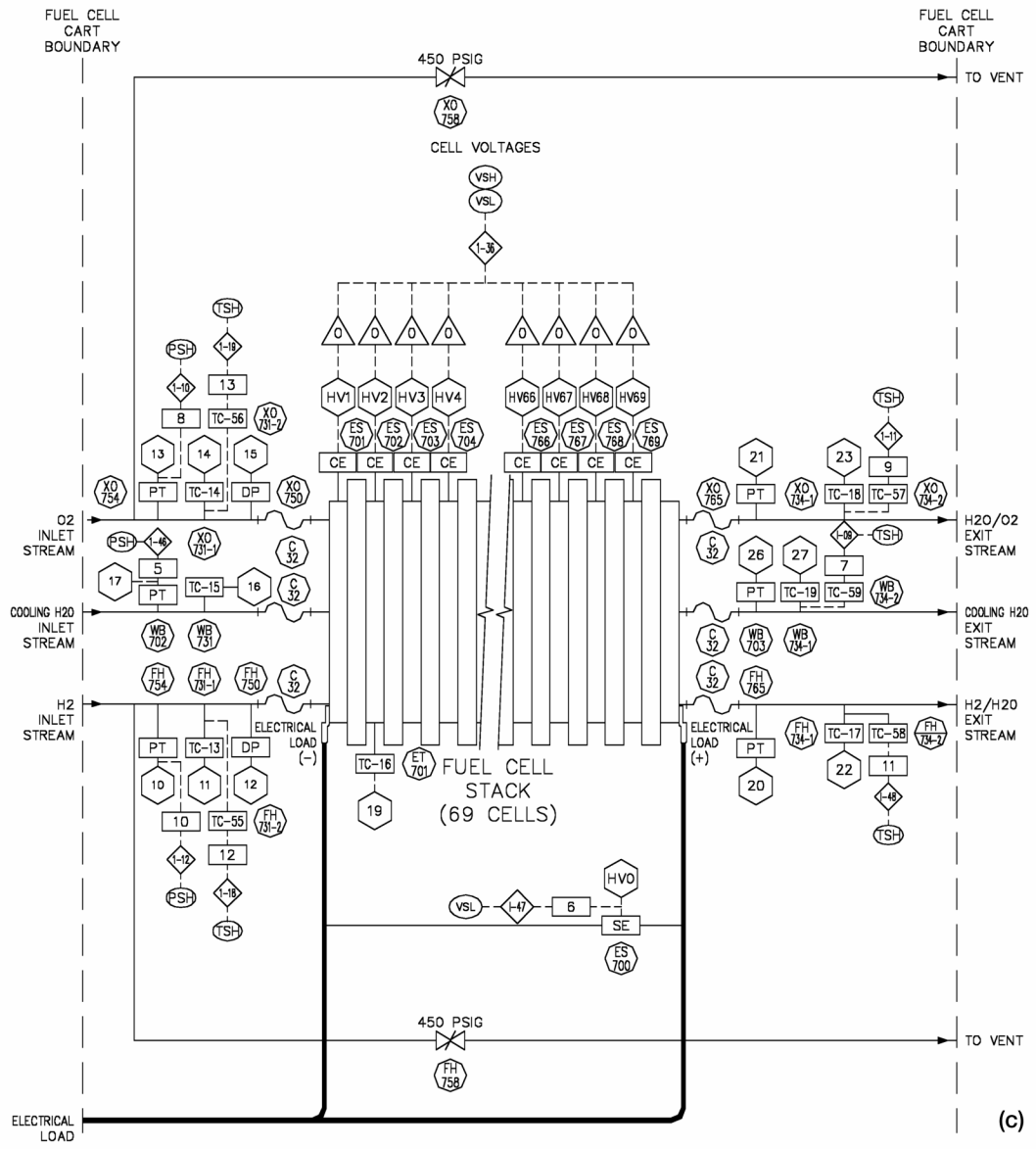

Figure 1.—Continued. (c) Test article and instrumentation.

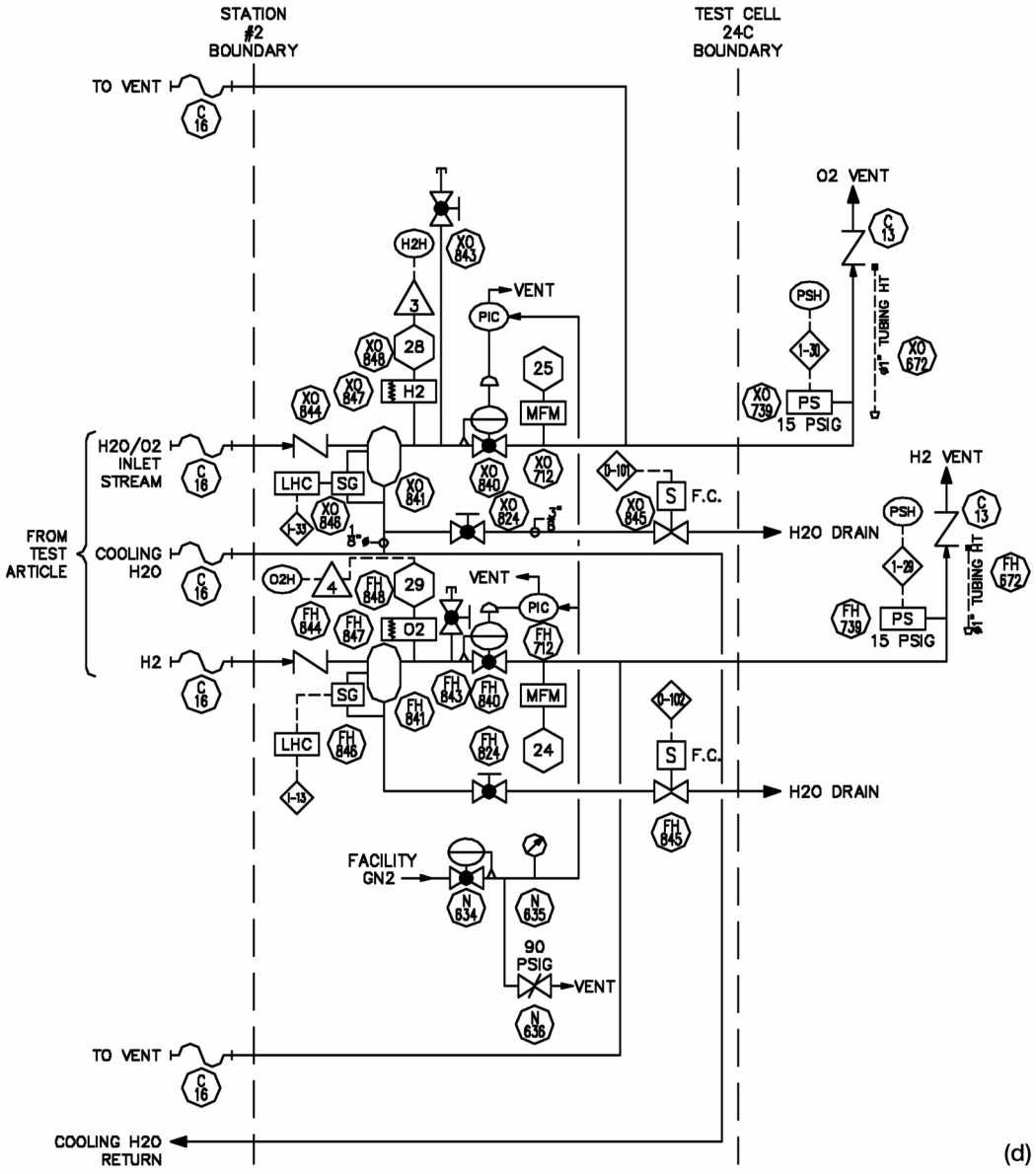

Figure 1.—Concluded. (d) Exit stream phase–sep., pressure control and venting.

standards for systems utilizing hydrogen and pure oxygen compressed gasses (Refs. 1 to 5).

Figure 2 shows a recent photograph of the cell 24 interior. The fuel cell stack test stand is in the foreground with the test article mounted.

Main purpose of this test stand is to make detailed open loop characterizations of multi-cell stacks controlling the input parameters and applied loads (see Table 1, "Applied Conditions") while measuring, observing, and recording the performance parameters listed in "Output Measurements." The data are compared with theoretical performance predictions traceable to the stacks' physical design, or the developer's performance predictions, or performance noted for similar stacks made by others.

Of particular interest to a fuel cell system designer are

- polarization performance at operational temperature and pressure
- operational life and performance consistency/ repeatability over time

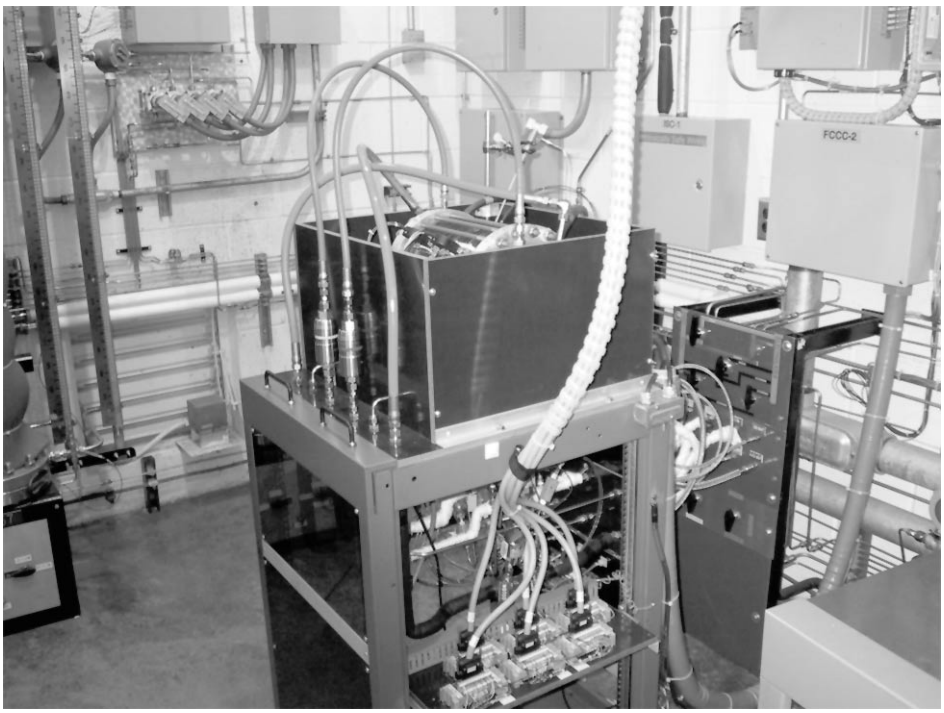

Figure 2.—Lynntech G3 fuel cell stack on RCL24 test stand at NASA GRC 26 Feb. 2003.

TEST ARTICLE

The fuel cell stack tested was a 64-cell hydrogen oxygen PEM unit designed and built by Lynntech, Inc. (College Station, Texas) designated "Generation III" in reference to its place in that company's continuing design evolution. Lynntech is the industry partner furnishing stacks for the Aerovironment "Helios" solar electric aircraft RFC demonstration; their stack design has undergone several revisions and improvements since the original concepts, realized in the form of a 4-cell developmental short stack, were tested in early 2000. These improvements were the product of careful failure analysis and rework following extensive testing at Lynntech, Aerovironment, and GRC.

From earlier designs such as the predecessor Gen II 4-cell short stack which was tested at GRC in September 2000, there emerged a more consistent performing short stack configuration in 2001 which was tested to failure in May 2001, then rebuilt and tested to failure again in June 2001, and again in October 2001 (Ref. 6). The short stacks had consistently good electrochemical performance but were subject to some MEA failures and crossover. The failure mechanism was eventually isolated and solved, and a modified Generation III short stack tested in January 2002 showed generally robust behavior and no more recurrences. Further testing in February 2002 confirmed performance and reliability of the new configuration.

Following success with the short stacks, Lynntech moved forward with construction of a full size 64-cell stack (the test article) which they operated at full power for 100 hr before delivering it to Aerovironment in February 2002 (Ref. 7). The stack was used to support AV's Helios prototype RFC pod demonstration in March 2002 (Ref. 8). Following a successful pod demonstration, the stack was removed and shipped to GRC for further evaluation.

GRC tested the stack in December of 2002 but the tests were curtailed by test stand problems including inadequate stack cooling and oxygen flows. These problems were fixed during January and February of 2003, and the stack was returned to the stand for testing during the week of February 17, 2003. Testing began February 19 and was completed February 27, 2003.

TEST NARRATIVE, RESULTS, AND DISCUSSION

The stack was subjected to "non-operational" performance tests February 19th prior to being operated

on the stand. The stack passed the no-op tests; all diagnostic parameters were within the developer's acceptable limits.

The stack was then connected to the test stand and energized with reactant gasses. As hydrogen and oxygen reactants were absorbed into the stack displacing purge nitrogen, the following open circuit voltage profile shown in Figure 3 began to emerge. The low cell to cell voltage variation observed also indicated a healthy stack.

Non-op tests were repeated February 25th prior to operational testing. Readings were close to those observed February 19th. With reactant flows established, the stack was then pressurized to 50 psig and electrical loads were applied. Then the pressure was raised to 70 psig, and load currents to a maximum of 100 A were applied to the stack. At 100 A some of the cells began to flood and could not sustain 100 A for more than 5 minutes, so oxygen flow rate was raised to the maximum (reduce utilization) in hopes of stabilizing the water balance in those cells. Keeping high inlet oxygen flow (50 SLPM) allowed the stack to sustain stable operation at 80 A. After stable operation was demonstrated at 70 psig, pressure was reduced to 50 psig and stable operation was again demonstrated at 80 A load current. Then, pressure was increased to 100 psig and a third stable operating point at 80 A was demonstrated. Figure 4 shows the cell voltage profile at a load current of 80 A. The stack was operated at this condition for approximately 45 minutes.

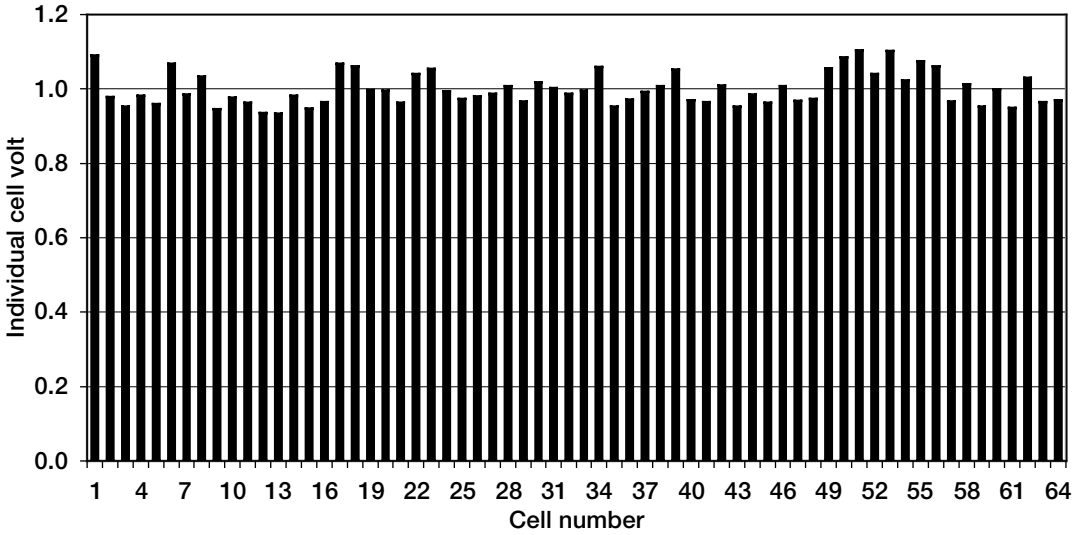

Figure 3.—Open circuit voltage profile with reactants flowing.

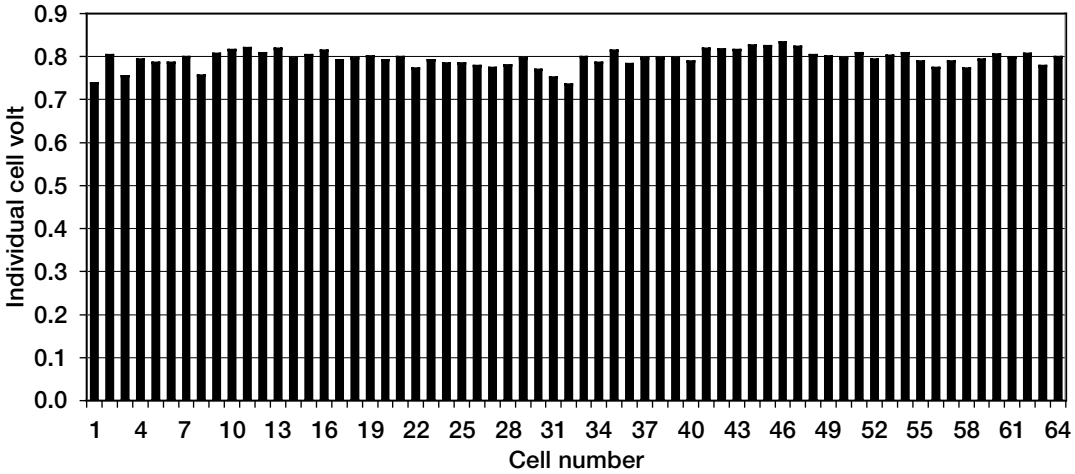

Figure 4.—Stack voltage profile at 100 psig, 80 A load.

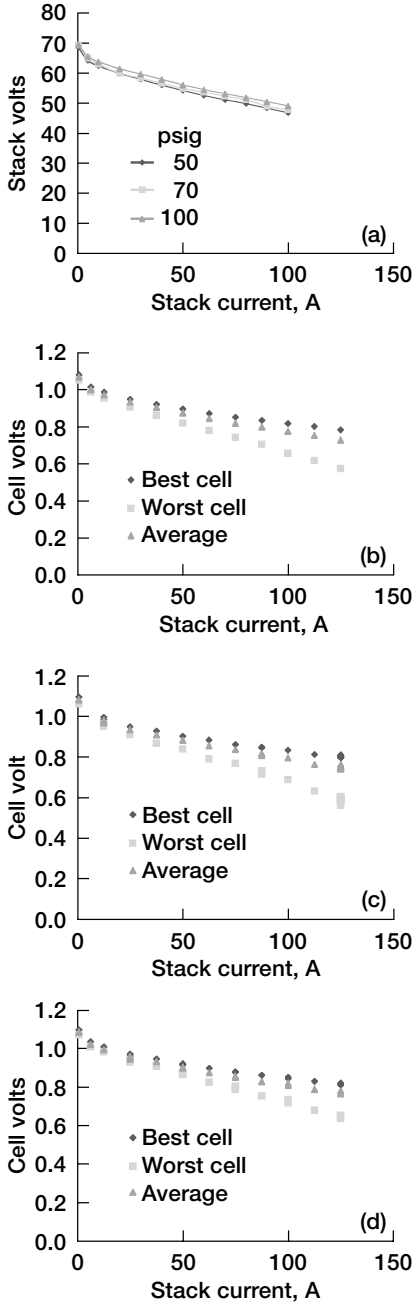

Figure 5.—(a) Lynntech G3 stack at 57 °C. Stack polarization performance at nominal conditions. (b) Polarization at 50 psig, nominal conditions—best, worst, and average cell performance. (c) Polarization at 70 psig, nominal conditions—best, worst and average cell performance. (d) Polarization at 100 psig, nominal conditions—best, worst and average cell performance.

The stack was then subjected to polarization performance tests at 50 psig and 100 psig. During these tests, electrical load was increased from idle in steps of 10 A, to a maximum current of 100 A, then stepwise

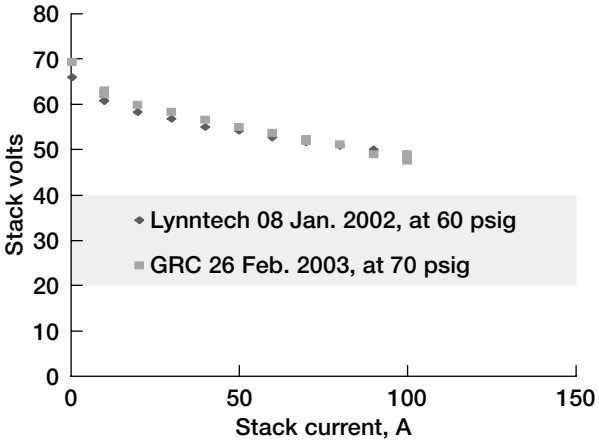

Figure 6.—Stack polarization comparison to earlier tests.

downwards in 10 A steps from 100 A back to idle. The test was also applied in reverse order, beginning with the maximum current and stepping down to idle and back in 10 A steps. The resulting cell and stack voltage versus current profiles were tabulated and are presented in Figures 5(a) to 5(d).

The polarization curves shown in these figures are the primary representations by which the electrochemical performances of similar stacks may be compared. For example it is useful to compare the 50 psig polarization performance recorded at GRC (Fig. 5(a)) with the 60 psig performance reported by the developer after 100 hr of acceptance testing 18 months ago (data from Fig. 4 of Ref. 7), which is plotted alongside the more recent data in Figure 6.

For a measurement of stack degradation we may look at the variation of individual cell voltages that were recorded during an individual polarization test, and compare with earlier polarization test data. For example, Figure 5(c) shows the best, worst, and average cell voltages recorded at GRC for the stack at 70 psig. Figure 7 (reproduced from Fig. 5 of Ref. 7) shows the individual cell voltages that were recorded by the developer under similar conditions approximately one year earlier. The plot shows all the individual cell voltages but its envelope is bounded by the best and worst performing cells. From comparison of Figure 5(c) to Figure 7 it appears overall stack degradation has remained less than ten percent, but best-to-worst cell voltage spread has approximately doubled.

Following polarization testing the stack was subjected to an endurance run at 100 psig, carried out during the afternoon of February 26. Run duration was limited by the available hydrogen supply (2 full "K" bottles) which

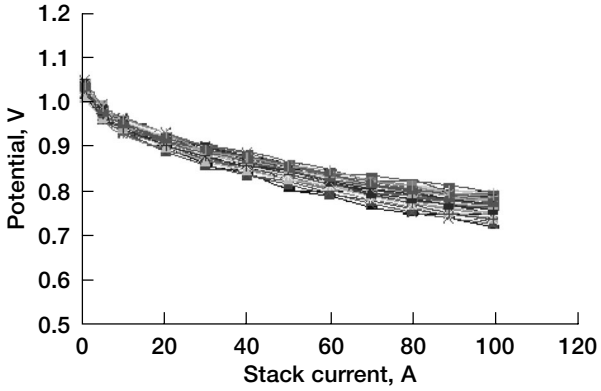

Figure 7.—Stack developer's "Individual cell IE curves, 60 psig, after 100 hours operation" reproduced from Ref. 7.

was exhausted after 4.5 hr of running. The run conditions were maintained at 80 A output for approximately 4.5 hr.

On the following day, the stack was subjected to non-op tests to ascertain health status. The non-op tests indicated the stack had suffered no damage during the tests, and was fully capable of continued operation.

CONCLUSIONS

The good electrochemical performance exhibited by this stack after several cycles of inactivity, and the limited degradation that was observed, indicates the stack is capable of supporting closed loop operation in a regenerative fuel cell system. The stack was removed from test stand on March 4, 2003, capped off, and transported to the Bldg. 135 closed loop test rig for integration into the regenerative fuel cell system.

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13. ABSTRACT ***(Maximum 200 words)***

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